REMARKS

Applicant respectfully requests reconsideration of this application as amended. Claims 1-3, 5-16, 18-21, 23-46, 48-53, 55-60, 62-67, 69-72, and 74-75 remain in this application. Claims 1, 7, 14, 18, 24, 31, 37, 43, 50, 57, 64, and 71 have been amended. No claims have been canceled. No new claims have been added.

Rejections under 35 U.S.C. § 103(a)

The Office Action rejected claims 1-3 and 5-6 under 35 U.S.C. § 103(a) as being unpatentable over Golmie et al., "A Differenctiated Optical Services Model for WDM Networks" (hereinafter "Golmie") in view of Assi et al., "Optical Networking and Real-Time Provisioning: An integrated Vision for the Next-Generation Internet" (hereinafter "Assi") and Kodialam et al., US Patent Application Publication No. 2002/0018264 A1 (hereinafter "Kodialam").

Golmie describes "a QoS service model in the optical domain ... based on a set of optical parameters that captures the quality and reliability of the optical lightpath." (Golmie, Abstract and Table 1.) An optical lightpath being "an optical communication channel, traversing one or more optical links, between a source-destination pair." (Golmie, Page 69, Left column.) Golmie classifies lightpaths (not wavelengths or paths) based on QoS and these classes for example "consist[] of three alternate lightpaths between a single source-destination pair accessible at the WADM, each with a unique DoS class, labeled class 1, class 2, and class 3, containing wavelength groups (λ_1, λ_2), (λ_3, λ_4), and (λ_5, λ_6) respectively... All lightpaths in a DoS class have equivalent quality of optical service between a source-destination pair." (Golmie, page 72, Left column.) Golmie does not describe determining service level topologies. (See Office Action, page 3.)

Assi describes two dynamic algorithms to help with the so-called "routing and wavelength assignment (RWA) problem." (Assi, page 38, right column.) In both

algorithms, a network with multiple nodes/OXCs (without wavelength conversion) is interconnected and "all nodes maintain a synchronized and identical topology and link state information (traffic engineering database, TED)." (Assi, page 39, right column.) "[T]he network is represented by W identical graphs, each conforming to the physical topology and a particular wavelength." (Assi, page 40, left column.) "For a given connection request, a constraint route is calculated, for each of the wavelength graphs, throughout the entire network from source to destination, typically using a shortest path algorithm but with link weights adjusted to attain some sort of local resource optimization." (Assi, page 40, left column.) Accordingly, each node of the network has the same physical topology database for the network. These nodes do not store what paths or wavelengths are available from a given node's perspective. Rather, in response to a connection request, all of the different paths from a source node to a destination node are calculated on the fly and the best path chosen from the calculated paths.

Kodialam describes "dynamic routing (IDR) of service level (e.g., bandwidth) guaranteed paths for network tunnel paths..." (Kodialam, Abstract.) "IDR determines whether to route an arriving request for a network tunnel path over the existing topology or to open a new, available optical wavelength path." (Kodialam, Abstract.) "[E]ach LSP [label switched path] determined route is computed at the local ingress router without communication with a domain or area wide router-server in communication with all routers of the nodes in the network....In employing OSPF and its extension, the topology information may be derived from the link sate database, with residual capacities derived using messaging and signaling methods..." (Kodialam, Paragraph 0041.) The network of Kodialam may have OXCs with or without wavelength conversion capability. (Kodialam, Paragraphs 0045-0046.) Kodialam discloses layering a logical internet protocol (IP) network over the physical optical network.

Thus, the combination of Golmie, Kodialam, and Assi is a QoS service model in the optical domain based on a set of optical parameters that captures the quality and

reliability of an optical lightpath (not paths and wavelengths individually) and uses OSPF-TE to determine the physical network topology for the entire system which is stored in each node of the network. In this model, each node has the same database that contains information about the all of the nodes of entire network and is not specific to just that particular node. This database information would include information about lightpaths separated by class for the entire area and would not be specific to a particular access node. However, the combination does not teach or suggest a service level topology that is a network topology smaller than the physical network topology and said each service level topology comprises connectivity between pairs of nodes only for the corresponding service level.

Thus, this combination does not describe claim 1, as amended:

> applying a set of one or more connectivity constraints that include quality of service (QoS) based criteria on a physical network topology of a wave length division multiplexing optical network to divide said optical network into separate service levels; and
> determining service level topologies for each of said service levels for each node in the optical network, , wherein each service level topology is a network topology smaller than the physical network topology and said each service level topology comprises connectivity between pairs of nodes only for the corresponding service level.

As stated in the Office Action, the Examiner admits that Golmie does not teach or suggest determining service level topologies. (Office Action, Page 2.) Thus, Golmie cannot teach or suggest a service level topology is a network topology smaller than the physical network topology and said each service level topology comprises connectivity between pairs of nodes only for the corresponding service level. Kodialam simply describes that a network could have either conversion free OXCs or conversion OXCs and layers an IP network over an optical network. Assi describes adaptive routing solutions in a conversion free network. Because neither Kodialam nor Assi relate their

concepts to a service level, neither Kodialam nor Assi teach or suggest a service level topology that is a network topology smaller than the physical network topology and said each service level topology comprises connectivity between pairs of nodes only for the corresponding service level as claimed.

The above quoted limitations are not described or suggested by Golmie, Kodialam, or Assi. While there are various uses for the invention as claimed, several such uses are discussed in Figure 3A-3C and paragraphs 0064-0069. Thus, while the invention is not limited to the uses discussed on these pages, it should be understood that Golmie, Kodialam, and/or Assi does not enable these uses and the above quoted limitations do.

Accordingly, the combination of Golmie, Kodialam, and Assi does not describe what Applicants' claim 1 requires. Claims 2-3 and 5-6 are dependent upon claim 1 and are therefore allowable for at least the same reason.

The Office Action rejected claims 7-9 under 35 U.S.C. § 103(a) as being unpatentable over Golmie in view of Kodialam et al., US Patent Application Publication No. 2002/0018264 (hereinafter "Kodialam"). The combination of Golmie and Kodialam does not describe what Applicants are claiming.

Thus, the combination of Golmie and Kodialam is a QoS service model in the optical domain based on a set of optical parameters that captures the quality and reliability of an optical <u>lightpath</u> (not paths and wavelengths individually) and uses <u>OSPF-TE to determine physical network topologies for the entire system</u>. As per above, neither Golmie nor Kodialam teach or suggest that a "<u>service level topology</u> [that] is a <u>network topology smaller than the physical network topology</u> and said each service level topology comprises connectivity between pairs of nodes only for the corresponding service level". However, claim 7 requires "for each of said plurality of service levels, maintaining service level connectivity from each node to other nodes of the wave length

division multiplexing optical network based on a conversion criteria, wherein each service level topology is a network topology smaller than the physical network topology and said each service level topology comprises connectivity between pairs of nodes only for the corresponding service level."

Accordingly, the combination of Golmie and Kodialam does not describe what Applicants require in claim 7. Claims 8-9 are dependent upon claim 7 and are therefore allowable for at least the same reason.

The Office Action rejected claims 14-16 under 35 U.S.C. § 103(a) as being unpatentable over Golmie et al., "A Differenctiated Optical Services Model for WDM Networks" (hereinafter "Golmie") in view of Assi et al., "Optical Networking and Real-Time Provisioning: An integrated Vision for the Next-Generation Internet" (hereinafter "Assi") and Kodialam et al., US Patent Application Publication No. 2002/0018264 A1 (hereinafter "Kodialam").

Thus, the combination of Golmie, Kodialam, and Assi is a QoS service model in the optical domain based on a set of optical parameters that captures the quality and reliability of an optical lightpath (not paths and wavelengths individually) and uses OSPF-TE to determine the physical network topology for the entire system which is stored in each node of the network. In this model, each node has the same database that contains information about the all of the nodes of entire network and is not specific to just that particular node. This database information would include information about lightpaths separated by class for the entire area and would not be specific to a particular access node. However, as per above, the combination does not teach or suggest a service level topology is a network topology smaller than the physical network topology and said each service level topology comprises connectivity between pairs of nodes only for the corresponding service level.

For example, claim 14, as amended, requires, "... at least one separate network topology database for each of said plurality of service levels that represents the connectivity between nodes of said optical network using those of the wavelengths that qualify for that service level, wherein each access node of said optical network stores a separate one of said network topology databases for each of said plurality of service levels, and <u>wherein each service level topology is a network topology smaller than the physical network topology and said each service level topology comprises connectivity between pairs of nodes only for the corresponding service level</u>."

Accordingly, the combination of Golmie, Kodialam, and Assi does not describe what Applicants' claim 14 requires. Claims 15-16 are dependent upon claim 14 and are therefore allowable for at least the same reason.

The Office Action rejected claims 18-21, 24-25, 31-32, 34, 43-47, and 49 under 35 U.S.C. § 103(a) as being unpatentable over Golmie in view of Assi and Kodialam.

The combination of Golmie, Kodialam, and Assi is a QoS service model in the optical domain based on a set of optical parameters that captures the quality and reliability of an optical <u>lightpath</u> (not paths and wavelengths individually) and uses <u>OSPF-TE to determine the physical network topology for the entire system which is stored in each node of the network.</u> In this model, each node has the same database that contains information about the all of the nodes of entire network and is not specific to just that particular node. This database information would include information about lightpaths separated by class for the entire area and would not be specific to a particular access node. However, as per above, <u>the combination does not teach or suggest a service level topology structure that is smaller than the physical topology of the optical network</u>.

The combination does not describe what Applicants' claims 18, 24, and 31 require. For example, claim 18, as amended, requires "for each access node of said optical network, a service level topology structure for each of said plurality of service

levels representing connectivity of that access node to others of said access nodes using wavelengths from the link service level channel sets of that service level, wherein each access node stores those of said service level topology structures representing connectivity of that access node, and wherein <u>said topology structures is smaller than a physical network topology of said optical network</u>."

Furthermore, claim 24, as amended, requires "a service level connectivity database to store, for each of said set of service levels, a service level topology structure that stores a representation of the service level topology of that service level for said access node, wherein the <u>service level topology is smaller than a physical network topology of said optical network</u>."

In addition, claim 31, as amended, requires "for each of said plurality of service levels, instantiate a service level topology structure, wherein <u>each service level topology is a network topology smaller than the physical network topology</u> and said each service level topology comprises connectivity between pairs of nodes only for the corresponding service level"

Accordingly, the combination of Golmie, Assi, and Kodialam does not describe what Applicants require in claims 18, 24, and 31. Claims 19-23, 25-30, and 32-36 are dependent upon claim 18, 24, and 31 are therefore allowable for at least the same reason.

The Office Action rejected claims 37-38, 40, 50-53, 56, and 71-73 under 35 U.S.C. § 103(a) as being unpatentable over Golmie, Assi, and Kodialam as applied to claims 18-20, 22, 24-25, 31-32, and 34, and further in view of Freeman, "Telecommunication System Engineering" (hereinafter "Freeman"). Freeman describes to store method steps as program memory for providing instructions to a controller or computer.

The combination of Golmie, Kodialam, Assi, and Freeman is a QoS service model in the optical domain based on a set of optical parameters that captures the quality

and reliability of an optical lightpath (not paths and wavelengths individually) and uses OSPF-TE to determine the physical network topology for the entire system which is stored in each node of the network. In this model, each node has the same database that contains information about the all of the nodes of entire network and is not specific to just that particular node. This database information would include information about lightpaths separated by class for the entire area and would not be specific to a particular access node. However, as per above, the combination does not teach or suggest a service level topology that is a network topology that is smaller than the physical network topology.

The combination does not describe what Applicants' claims 37, 50, and 71 require. For example, claim 37, as amended, requires "... for each of said plurality of service levels, instantiate a service level topology structure, wherein each service level topology is a network topology smaller than the physical network topology and said each service level topology comprises connectivity between pairs of nodes only for the corresponding service level ..."

Furthermore, claim 50, as amended, requires "selecting a path and a wavelength on said path using a database that stores, for each of the plurality of service levels, a representation of available paths from the source node to other access nodes in said optical network and a separate service level topology structure for each of said service level topologies of said source node, wherein each path is a series of two or more nodes connected by links having a set of one or more wavelengths at the same service level, and wherein said separate service topology structure is smaller than a physical network topology of said optical network".

In addition, claim 71, as amended, requires "a service level connectivity database for an access node of a wave division multiplexing optical network, wherein each link of said optical network includes a set of zero or more lamdas for each of a plurality of service levels, each of said plurality of service levels includes a set of zero of more

possible end to end paths comprised of a series of one or more links that include one or more lamdas of that service level, wherein the service level connectivity database includes a separate service level topology structure for each of said plurality of service levels, wherein said separate service topology structure is smaller than a physical network topology of said optical network, each of said plurality of service level topology structures storing the data for each of the possible end to end paths of that service level that end with said access node, said service level connectivity database including, for each of the possible end to end paths that end with said access node, data representing, the series of links of that path; and the lamdas of that path."

Accordingly, the combination of Golmie, Assi, Kodialam, and Freeman does not describe what Applicants require in claims 37 and 50. Claims 38-42, 51-53, 55-56, and 72-73 are dependent upon claims 37 and 50 and are therefore allowable for at least the same reason.

The Office Action rejected claims 30 and 57-60 under 35 U.S.C. § 103(a) as being unpatentable over Golmie, Assi, and Kodialam in view of Melaku et al., US Patent Publication No. 2003/0074443 (hereinafter "Melaku").

Melaku describes rerouting traffic to a different path based on a change in QoS requirements. (Melaku, Paragraph 0056.) "If the user decides to change QoS requirements in the midst of a session, the LMQB [Last Mile QoS Broker] dynamically updates the database [of the LMQB] and re-allocates new resources and establishes a path that meets the requested quality of service." (Melaku, Paragraph 0056.)

The combination of Golmie, Kodialam, Assi, and Melaku is a QoS service model in the optical domain based on a set of optical parameters that captures the quality and reliability of an optical lightpath (not paths and wavelengths individually) and uses

OSPF-TE to determine the physical network topology for the entire system which is stored in each node of the network. In this model, each node has the same database that contains information about the all of the nodes of entire network and is not specific to just that particular node. This database information would include information about lightpaths separated by class for the entire area and would not be specific to a particular access node. However, the combination does not teach or suggest a service level topology structure that is smaller that a physical network topology of the optical network.

The combination of Golmie, Assi, Kodialam, and Melaku does not describe what Applicants require in claim 57. For example, claim 57, as amended, requires "selecting a path and a wavelength on said path using a database that stores, for each of the plurality of service levels, a representation of available paths from a source node of said communication path to other access nodes in said optical network and a separate service level topology structure for each of said service level topologies of said source node, wherein each path is a series of two or more nodes connected by links having a set of one or more wavelengths at the same service level, and wherein said separate service topology structures is smaller than a physical network topology of said optical network …".

Accordingly, the combination of Golmie, Assi, Kodialam, and Melaku does not describe what Applicants require in claim 57. Claims 58-60 and 62-63 are dependent upon claim 57 and are therefore allowable for at least the same reason.

The Office Action rejected claims 64-67 and 69-70 under 35 U.S.C. § 103(a) as being unpatentable over Golmie, Assi, Kodialam, and Freeman in view of Melaku as applied to claims 57-60, and further in view of Freeman.

The combination of Golmie, Kodialam, Assi, Freeman, and Melaku is a QoS service model in the optical domain based on a set of optical parameters that captures the quality and reliability of an optical lightpath (not paths and wavelengths individually) and uses OSPF-TE to determine the physical network topology for the entire system which is stored in each node of the network. In this model, each node has the same database that contains information about the all of the nodes of entire network and is not specific to just that particular node. This database information would include information about lightpaths separated by class for the entire area and would not be specific to a particular access node. Additionally, this common database may be updated dynamically in each node to reflect QoS changes (each node will note the QoS changes). However, the combination does not teach or suggest a service level topology structure that is smaller that a physical network topology of the optical network.

The combination of Golmie, Kodialam, Assi, Freeman, and Melaku does not describe what Applicants require in claim 64. For example, claim 64, as amended, requires "responsive to receiving a request to change a service provisioned with a communication path established in a wavelength division multiplexing optical network at one of a plurality of service levels to a different one of said plurality of service levels, selecting a path and a wavelength on said path using a database that stores, for each of the plurality of service levels, a representation of available paths from a source node of said communication path to other access nodes in said optical network and a separate service level topology structure for each of said service level topologies of said source node, wherein different wavelengths on at least certain links of said optical network qualifying for different ones of said plurality of service levels forms a different service level topology for each of said plurality of service levels for each access node of said optical network, wherein each path is a series of two or more nodes connected by links having a set of one or more wavelengths at the same service level, and wherein said service topology structures is smaller than a physical network topology of said optical network"

Accordingly, the combination of Golmie, Assi, Kodialam, Freeman and Melaku does not describe what Applicants require in claim 64. Claims 65-67 and 69-70 are dependent upon claim 64 and are therefore allowable for at least the same reason.

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Respectfully submitted,

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A Novel Distributed Progressive Reservation Protocol for WDM All-optical Networks

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Abstract-In this paper, we propose and describe a new distributed reservation protocol for establishing lightpaths in WDM all-optical networks. Distributed control mechanisms are preferred and employed because of their advantages over centralized ones to set up virtual channels. The new protocol is a combination of the conservative and aggressive backward reservation protocols, which attempts to improve performance by adapting a reservation to network conditions and characters. On the one hand, the new protocol uses network circumstances and decides and applies a more conservative or aggressive approach. In other words, the protocol progressively fluctuates between those reservation protocols in order to capture their respective advantages. As a result, in extreme cases it acts exactly like either the conservative or the aggressive reservation protocol. On the other hand, it considers the characteristics of a network to set a retry-list size. As a result, a retry-list size is not determined by a fixed number but modified based on the multiplexing degree of a network, which prevents imposing ineffective retries on a network with a small number of wavelengths and instead encourages more retries for a network with numerous channels. Therefore, the proposed protocol transforms the static nature of existing reservation protocols into a more adaptive one in order to enhance network performance.

Index terms: Optical networks, wavelength division multiplexing networks, routing protocol, reservation protocol, distributed control.

1. INTRODUCTION

WDM was introduced and has been accepted as a new way to accommodate increasing demand for more bandwidth over fiber optic medium. This technique increases the data transfer carried over multiple wavelengths in a single fiber by dividing the capacity into several channels. It is also suggested that this technique can decrease the electronics bottleneck by supporting multiple channels, where each one operates at the peak rate of which electronic devices are capable [1].

In all-optical wavelength routed WDM networks, every pair of users communicates with each other by a predetermined channel, which is called a lightpath [2]. A lightpath may include one or more links. When setting up a lightpath, we need to configure various switches in a network. Generally in every network control and management protocols, including reservation techniques, are employed to configure the switches in the nodes through which the connections are routed. Control mechanisms are also used to tear down previous all-optical connections and change the status of the involved nodes. Control mechanisms can be either centralized or distributed [3, and 4]. While centralized control mechanisms are relatively simple and work well for static traffic, they are not scalable. For this reason, centralized control mechanisms are considered to be infeasible for dynamic traffic in large networks. On the other hand, distributed control mechanisms enhance reliability and scalability and thus, they are usually more robust than and preferable to centralized mechanisms. Control mechanisms also are needed to update routing tables and reflect the recent condition of all nodes. Two basic approaches, namely Path Multiplexing (PM) and Link Multiplexing (LM), are used to establish lightpaths in all-optical WDM networks [5, 6, and 7]. In PM, a lightpath is established by using the same wavelength that is available on all the links along the path. In LM, different wavelengths available on different links along the path can be used. To apply LM, we need wavelength converters at each router. Employing converters is an expensive approach and in addition, right now there is not a full-range converter in the market. Thus the majority of researchers have selected PM as the more practical approach. In this paper we always consider PM as the preferred method for setting up a path.

In general, there are two types of distributed reservation protocols for setting up lightpaths in all-optical WDM networks, namely forward and backward reservation protocols. In a *forward reservation protocol*, the source node decides on a route to the destination node and initiates a reservation. After choosing the route, a forward reservation signal is sent to reserve a selected wavelength on all the links along the path. Passing through the predetermined path, the forward reservation signal configures related switches to make the lightpath. Once the reservation signal successfully reaches the destination, it informs the source node that it has accomplished the reservation by sending an acknowledgement packet back to the source. Subsequently, the source node is authorized to start transmitting data through the reserved lightpath. In a source-routed backward reservation protocol, again the source node selects a route to the destination node but in contrast with forward reservation, it does not start a reservation from the source node. Instead of forwarding a reservation packet to the destination, a probe packet is launched to gather the most recent information about wavelengths without doing any wavelength reservation. As soon as the probe packet reaches the destination, one of the free wavelengths is picked and a

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backward reservation packet starts reserving the inverse path all the way to the source. Fig. 1 illustrates the main differences between forward and backward reservation protocols. The shaded area represents the period during which the wavelength has been locked but not utilized. It is obvious that in backward reservation protocol the shaded area has shrunk and the unused bandwidth is reduced. This is the result of initiating a reservation from a destination instead of source, which postpones utilizing bandwidth. Moreover, backward reservation protocol does not pick a wavelength blindly and decides based on the most updated information, which increases the chance of having a successful reservation [8 and 9]. Therefore, we focus on backward reservation protocol as a more developed and efficient protocol to be our source of comparison.

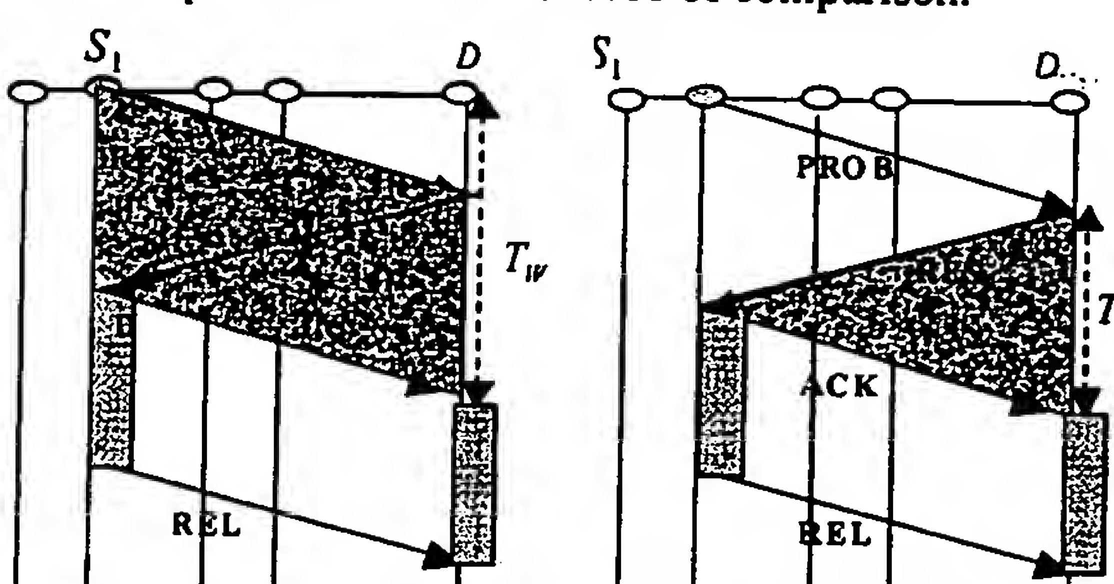


Fig. 1. a) The unused bandwidth in FRP. b) The unused bandwidth shrinks in BRP.

The rest of the paper is organized as follows: Section 2 reviews backward reservation protocol, and different types of it. In Section 3 we introduce our reservation algorithm in detail. In Section 4, the performance of our proposed method is evaluated, Section 5 presents simulation results, and section 6 concludes the paper.

2. BACKWARD RESERVATION PROTOCOL

A Backward Reservation Protocol (BRP) uses a forward control packet to find the available wavelengths in the network without locking them. A backward control packet then reserves one (or all) of the wavelengths found available. BRP needs five different types of control packets, as listed below:

- Probe packets (PROB). A source node sends a probe packet to the destination to gather information about wavelength usage without locking any wavelengths. A PROB packet carries a bit vector (wavelength-set) to represent the set of unoccupied wavelengths to establish the connection.
- Reservation packets (RES). A destination node picks up one (or all) of the wavelengths from the wavelength-set and sends a reservation packet.
- Negative Acknowledgement packets (NACK). An intermediate node sends a NACK packet to inform the source node of a reservation failure. Note that intermediate nodes do not need to take special action.
- Fail packets (FAIL). An intermediate node sends a FAIL packet to inform the destination node of a reservation failure. In the way, it releases the locked wavelength or wavelengths and amends their status.
- Release packets (REL). The same as in the forward reservation, they tear down a lightpath.

Of course in BRP, once a connection is established or tear down, the routing tables need to be amended. This is necessary to reflect correctly the current status of each link.

BRP employs one of two main approaches to start a reservation [5, 6, and 7]. The first, well-known mechanism, which is called *Conservative approach*, attempts to deal with one wavelength at a time. This means that the protocol chooses only one of the wavelengths available in the Wavelength-set. In the next stage, the protocol sends the dedicated reservation packet to set up a lightpath between the source and destination. If the reservation packet establishes the lightpath successfully, data will be transferred along with an encapsulating ACK packet. On the other hand, if the reservation packet cannot reserve the same wavelength all along the path, a failure signal returns to the destination and another wavelength is selected from the wavelength-set in order to set up the lightpath. This procedure repeats until the lightpath is established or all of the wavelengths are eliminated from the set (note that sometimes there is a restriction on the number of retries). It is obvious that this protocol does not lock all the available wavelengths and allows other requests to reserve the rest of the available wavelengths. The disadvantage is an increase in latency. Additional time will be required if a reservation procedure repeats several times. This dramatically decreases the performance of the system by causing a considerable delay. Thus to overcome the drawback involved in the first protocol, the second popular mechanism examines all the recourses at the time (note that there are some protocols that put limitations on the number of wavelengths that may be reserved at the same time. This alternative method is known as *Aggressive approach.* Using the aggressive mechanism, the reservation time is fixed and the system benefits from having less latency. However, this reduction comes at the price of over-locking the wavelengths. In other words, the protocol reserves all wavelengths, including those not needed for the current reservation and thus prevents other requests from accessing the wavelengths during the reservation period. Studies have shown that efficiency is enhanced if the system includes a mechanism called *Intermediate release mechanism* [9]. This means that whenever a node finds that a wavelength has already been identified as unavailable over one hop, an intermediate control packet is sent back through the partially reserved path to release the wavelength in the previous hops. This certainly consumes bandwidth in the control channel, but it increases the number of available wavelengths. Then the probability of other calls to set up their lightpath will increase. Thus, the overall performance of the network increases at the cost of a little control overhead.

As it has been explained before, each algorithm tries to increase throughput by either increasing efficiency or

decreasing latency. It is easy to see that both approaches act static and do not consider network conditions. To avoid the disadvantages of the conservative and aggressive BRP, we propose a new algorithm that acts dynamically and tries to select the best reservation approach based on network status.

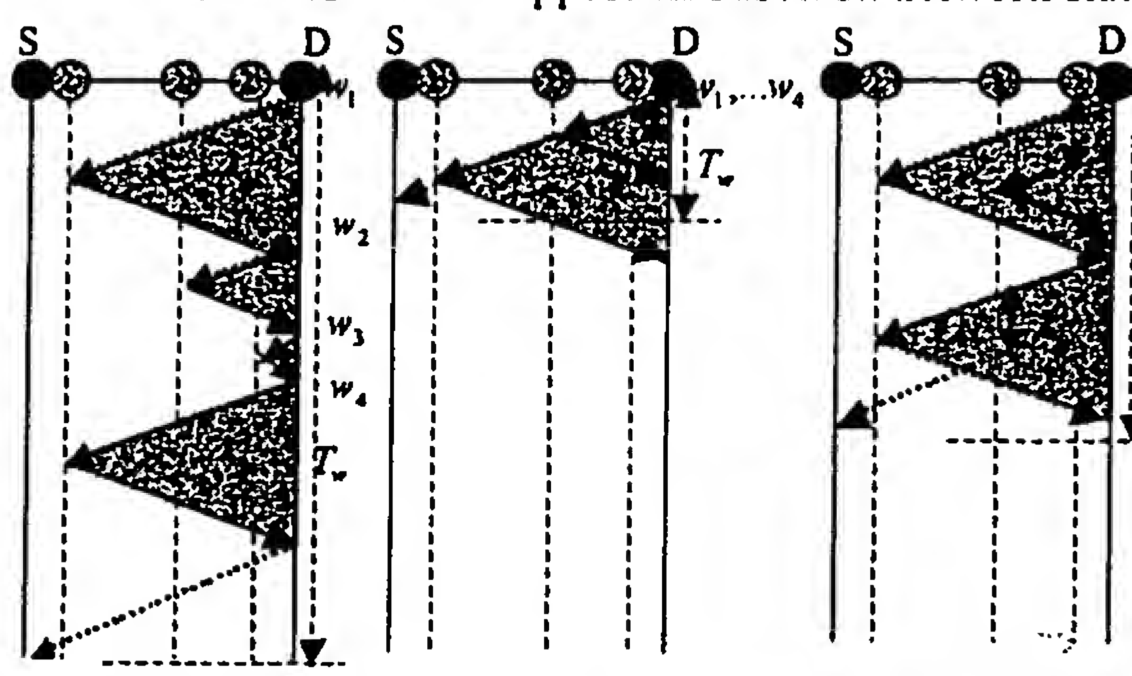


Fig. 2. a) An example of the conservative BRP. b) An example of the aggressive BRP. c) An example of PRP.

3. PROGRESSIVE RESERVATION PROTOCOL

In this section, we introduce our proposed protocol. The new protocol is called Progressive Reservation Protocol (PRP) and has a lot in common with the conservative and aggressive PRP. We consider that distributed control mechanisms are applied to establish lightpaths. In other words, there is not a master router available with global knowledge about all routers' states. Even with this assumption, we can have local knowledge in relation to the network. We will define this term by "local condition" of a path, in a network. This term indicates the traffic pattern between two end nodes through a virtual channel. Defining this term implies that there are equivalent number of requests and local condition in a network.

Moreover, the same as other backward reservation protocols, a wavelength-set is obtained by sending a probe packet from the source to the destination to specify unoccupied wavelengths. The wavelength-set can be interrupted as a recent traffic status of a path or local condition. In fact the size of wavelength-set is inverse proportional to the traffic load. In other words, heavily loaded network results in a shorter wavelength-set and a longer list reveals a light traffic through the path. Thus, a wavelength-set illustrates local condition of a lightpath.

PRP can be seen as a tradeoff between two existing reservation protocols, which rather than sending RES packets with zero interval time (similar to the aggressive BRP) or after receiving a failure signal (similar to the conservative BRP), defines the interval time between two consequent RES packets by a factor that is related to local condition of a call. Fig. 2 depicts the differences among the conservative BRP, the aggressive BRP and the proposed PRP. For the sake of simplicity, we consider an array network, which includes only five nodes. S and D show the source and the destination nodes respectively. Other unidentified nodes are intermediate nodes. We assume that there are four wavelengths, $w_1,\ldots,w_4$, in the wavelength-set. Each arrow represents a RES packet. We add a wavelength label on the right hand side of each arrow to signify a dedicated RES packet.

On the other hand, reservation protocols usually impose a rigid restriction on the size of wavelength-sets (a subset of the original wavelength-set is picked for starting a reservation). As a result, every wavelength-set is limited based on a fixed number. This means that the reservation protocols operate completely static without any perspective. The new protocol does not dictate any predetermined constraint on the size of wavelength-sets and adapts them to the multiplexing degree of a network. This permits reservations to try their chance based on network resources not a rigid limit. Therefore, PRP prevents from either impossible useless retries and undesirable burst when resources are limited or terminating reservations unsuccessfully and decline in throughput when resources are significant.

3.1 Control Packets

In general, the control packets are very similar to those used in BRP. There are six types of control packets PROB, RES, NACK, FAIL, REL, all with almost the same functionality as in BRP, plus a supplementary ACK packet. Every control packet contains a packet ID, which carries the identifier of the connection. Two control packets are said to be identical, if they have the same value in the ID field.

The points that distinguish between PRP and BRP will be clarified as we explained the purpose of each packet.

- A source node sends a PROB packet toward the destination to probe and collect information about wavelength usage without locking any wavelength along the path. A PROB packet carries ~~a bit vector~~ (wavelength-set), which embodies the set of available wavelengths to establish the connection. Note that the size of each wavelength-set could be different from other reservation wavelength-sets size, since it could have different local condition.
- In contrast with the aggressive BRP and similar to the conservative BRP, only one of the free wavelengths selects from the wavelength-set and the corresponding RES packet will be sent toward the source node.
- In the next stage, if the wavelength-set includes more than one wavelength, rather than waiting to observe the result of the first reservation packet (similar to the conservative approach), after a time interval a second identical reservation packet is transmitted to reserve the second available wavelength.
  - o The point is that the time interval is defined by local condition and varied for each reservation. It could be as large as the propagation delay between the source and the destination nodes (similar to the conservative approach) or it could shrink toward zero (the same as the aggressive approach).

- If a RES packet was not able to reserve a wavelength on a link, a failure packet, FAIL, is sent back to the destination. This packet releases already locked links and notifies the destination of a failure.
- The process of sending identical RES packets consecutively continues with the rest of available wavelengths until one of the wavelengths can be reserved all along the path and the virtual channel is established. In that case, an ACK is sent to inform the destination of the successful reservation. The ACK also terminates unfinished identical reservations (releases the associated locked links) and prevents the forwarding of those that have not been launched yet.
- A REL packet tears down the lightpath after transferring data.
- In the last step, if none of the wavelengths was able to make the path, the source node receives a NACK packet.

3.2 Properties

The benefit of PRP over the conservative BRP is that it inspects the probability of reserving more than one wavelength before rejecting one of them. Thus, PRP increases the likelihood of a reservation being fulfilled. Furthermore, PRP reaches a result sooner, which lessens the reservation delay time. On the other hand, since the protocol does not attempt to start the reservation by using all the available wavelengths, it avoids locking all wavelengths and blocking other requests during a reservation period. This gives the protocol an advantage over the aggressive type. It is obvious that PRP increases the control channel traffic. This is a consequence of adding an extra ACK packet and sending more than one RES packet to complete a reservation. The following are several points that enable us to disregard the negative effect of the extra burden on the control channel:

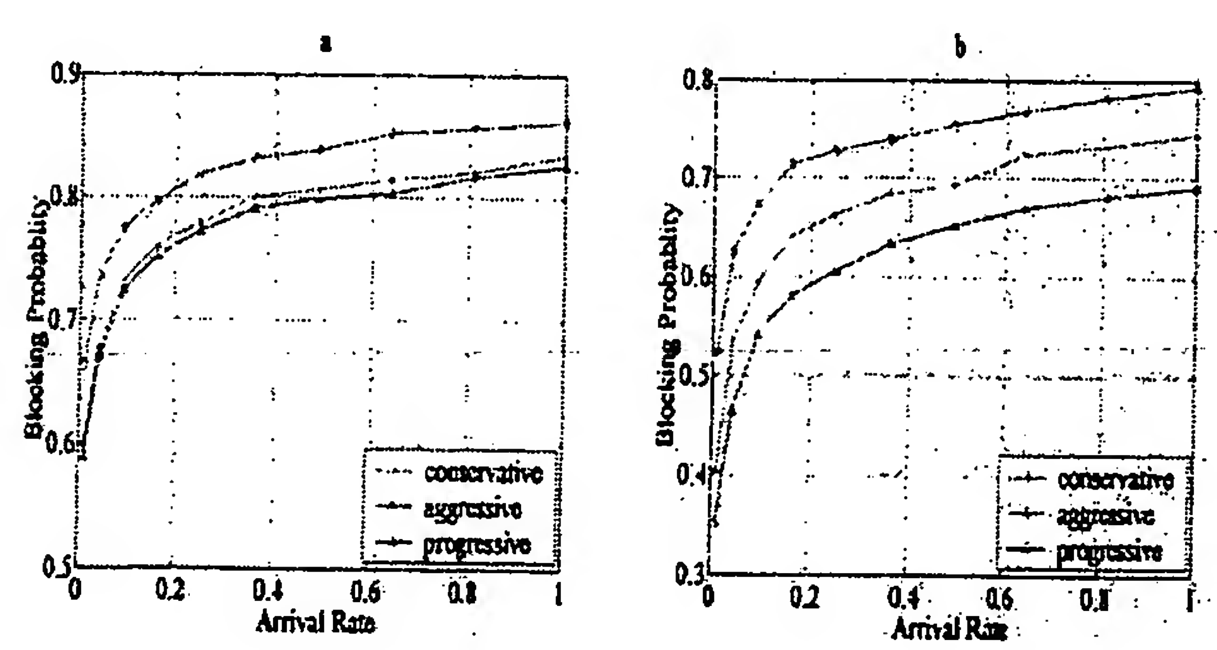
- On the whole, the control networks are under light traffic. Consequently, they can endure extra traffic without being congested and decreasing their throughput.
- The numbers of identical RES packets are limited.
- Only under low traffic, the size of wavelength-set is considerable and the number of RES packets is numerous. Meanwhile the traffic load is also low and the success probability is high. Thus, only part of a wavelength-set is examined.

4. SIMULATION

In this section, we use simulation to study the performance of PRP. We run the proposed algorithm against the conservative and aggressive BRP approaches. The simulation is executed for two types of networks, the less impact network (an array or bus network) and the most impact network (a hypercube network). Blocking probability is a measure for the performance evaluation of this work and is defined as the ratio of the number of calls blocked to the number of offered calls.

- *Arrival rate per node **R***: the connection requests are generated at each node according to a stationary Poisson process.
- *Multiplexing degree **W***: This indicates the virtual channels (wavelengths) supported by each link. In our simulation, this value has been set to 4 and 8.
- *Network size **N***: The simulation is run over array and hypercube networks for N=16, N=128.
- *Data size **D***: It is assumed that data lengths are not fixed and generates based on exponentially independent random variables. To avoid having almost zero size data, we add a small fixed amount to the data.
- *Initial retry-list* L_w: This parameter determines the initial size of a wavelength-set. The value has been set at 3 for the conservative and aggressive BRPs. This value is varied for each PRP reservation and specified by the local condition. To avoid lengthy wavelength-sets, we put an upper band of $W/2$ on L_w.
- *Timeout value*: This parameter indicates how long a RES signal in the control channel can be put on hold. This value has been set at zero. By setting this parameter at zero, we employ a dropping policy [4, 8].
- *Propagation delay* T_P: It is assumed that T_P is fixed for all adjacent nodes.
- *S-D hops* N_{rw}: Number of hops between S-D pairs.
- *Time interval* α: this term specifies the interval between two identical RES Packets in PRP. We consider $\alpha = (T_P N_{rw}) L_w / W$. Experience shows that this value results in the lowest blocking probability. The value of α is specified to be proportional to the related wavelength-set and the propagation delay S-D nodes. it is also inverse proportional to the maximum multiplexing degree of medium. Thus, the value of α could be varied between zero and the propagation delay between a pair of end nodes.

we assume a zero holding time. This means that if a RES packet was not capable of finishing its reservation, it is dropped instantly. Furthermore, an intermediate release mechanism is applied to unlock blocked wavelengths.



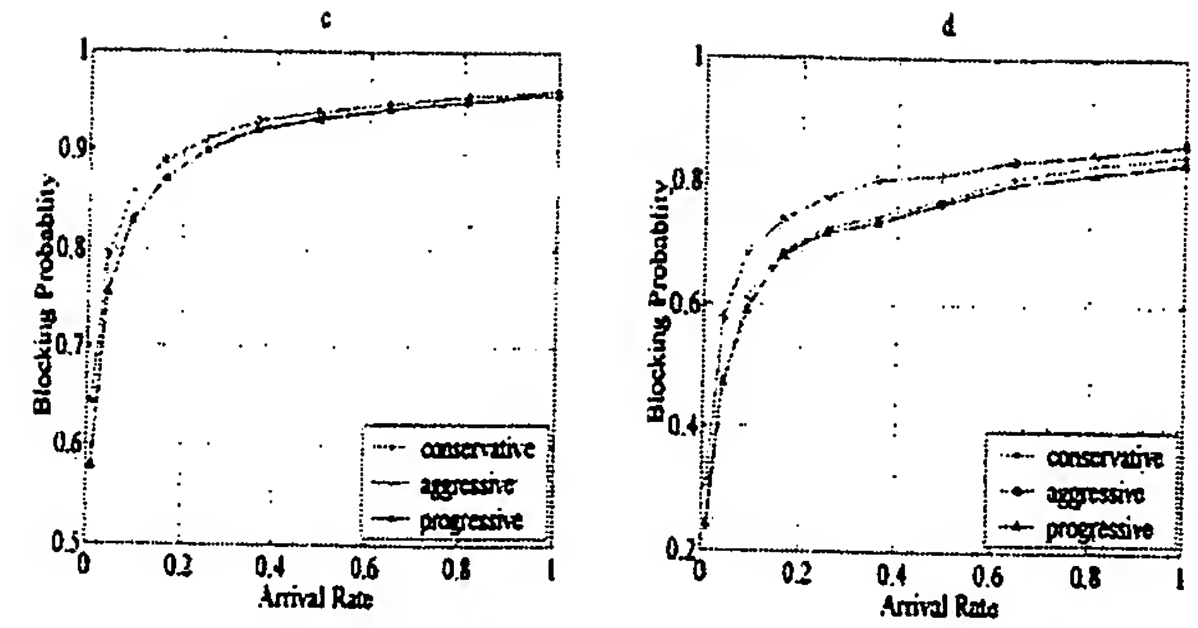


Fig. 3. The blocking probability curves of the three reservation protocols on different network size and multiplexing degree. a) An array network for N=16, W=4, b) An array network for N=16, W=8, c) An array network for N=128, W=4, d) An array network for N=128, W=8.

Two significant results of this section are following:

- If PRP is applied to a network with a small degree of connectivity, it reduces blocking probability more than other reservation protocols. Note that for a hypercube model, the conservative BRP reduces blocking probability more than others.
- As the number of virtual channels (multiplexing degree) is increased, PRP shows its superiority.

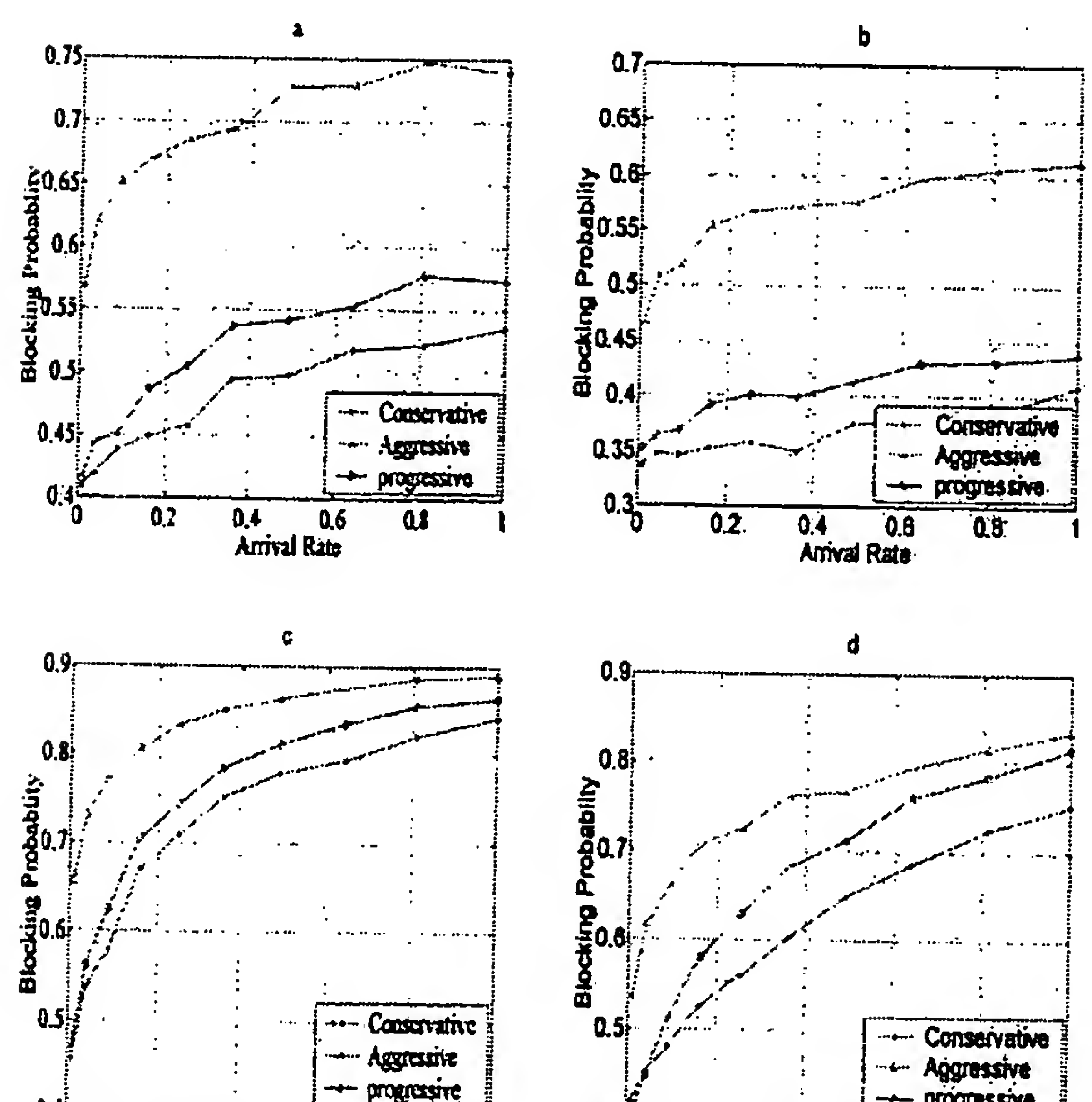


Fig. 4. The blocking probability curves of the three reservation protocols for different network size and multiplexing degree. a) A hypercube network for N=16, W=4, b) A hypercube network for N=16, W=8, c) A hypercube network for N=128, W=4, d) A hypercube network for N=128, W=8.

5. CONCLUSION

In this paper we introduce our novel progressive reservation protocol (PRP) to establish virtual channels in WDM all-optical networks. The new protocol attempts to increase performance by considering traffic conditions and characters. PRP applies a combination of existing reservation schemes. Depending on circumstances, the proposed protocol fluctuates between a more conservative and a more aggressive approach. Furthermore, it regards multiplexing degree and defines the size of retry-sets dynamically instead of using a predetermined fixed retry-set for different networks. We evaluate the new PRP and the aggressive and conservative BRP by simulation. The comparison reveals that PRP has less latency than the conservative BRP but more than the aggressive BRP. In fact, the latency of PRP rises and falls within that range. On the other hand, the new protocol decreases blocking probability more than other compared reservation protocols. we show that only for a hypercube model, it has greater blocking probability than the conservative BRP but still less than the aggressive BRP. This result comes at the price of adding more traffic to the control network.

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